The James Webb Space Telescope as a Technology Source for Terrestrial Planet Finder

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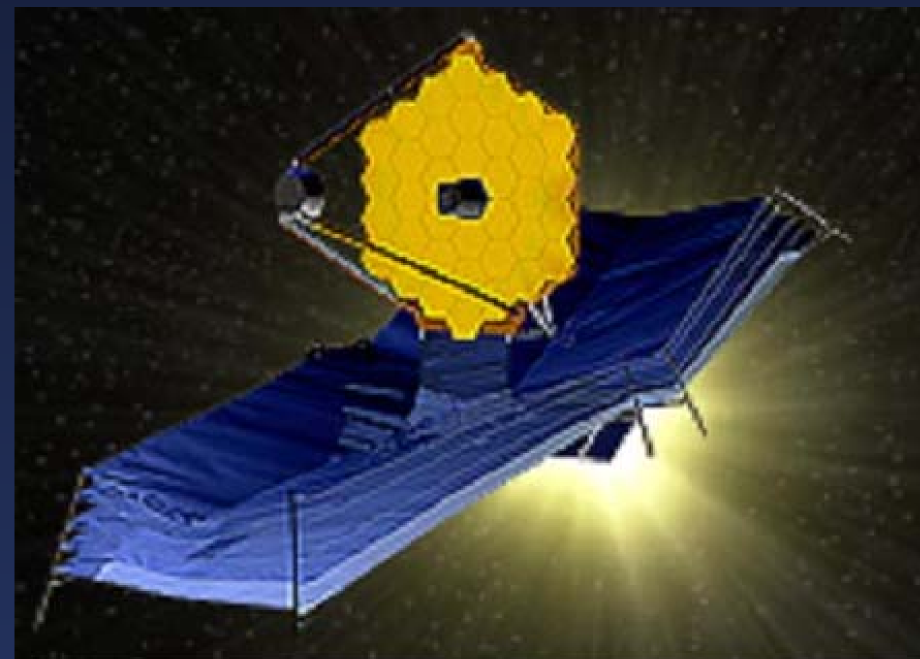
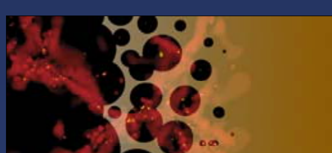
James Webb Space Telescope: The First Light Machine

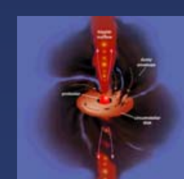
- Successor to Hubble Space Telescope
- Mission Objective: to observe the early universe and the formation of the first galaxies billions of years in the past
- Seven times HST collecting area
- Wavelength coverage: 0.6 to 28 microns
- Optical resolution: <0.1 arcsec
- Passively cooled to <40 Kelvin
- Launch 2011 to L2 halo orbit
- Lifetime: 5 to 10 years





Reionization

Early Galaxies



Stellar Genesis

Giant Planets

Parallels to Palomar

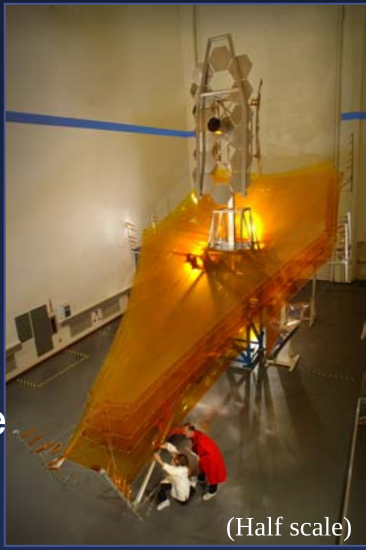
George Hale Telescope

Firsts

- Honeycomb Pyrex primary
- Horseshoe equatorial
- Serrurier truss tube
- Oil pad bearings
- Servo control
- "Facility" instrument

- 5.08m (200 inches)
- f/3.3
- 650 kg/m2
- 227,300 kg total
- First Light 1948

James Webb Space Telescope



Firsts

- Deployable Be optics
- Cryogenic space telescope in L2 orbit
- Large, deployed V-groove radiator sunshade
- Wavefront sensing and control
- Spacecraft isolation tower
- Large instrument module

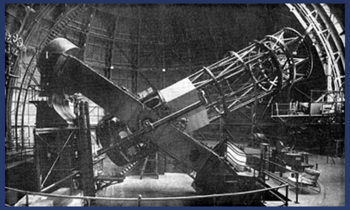
- 6.5m (256 inches)
- f/1.33
- 14.8 kg/m2
- 5890 kg total
- First Light 2011

4xA in 31 yrs

7xA in 25 yrs

John Hooker Telescope

- 2.5m (100 inches)
- f/5
- 830 kg/m2
- 79,100 kg total
- First Light 1917

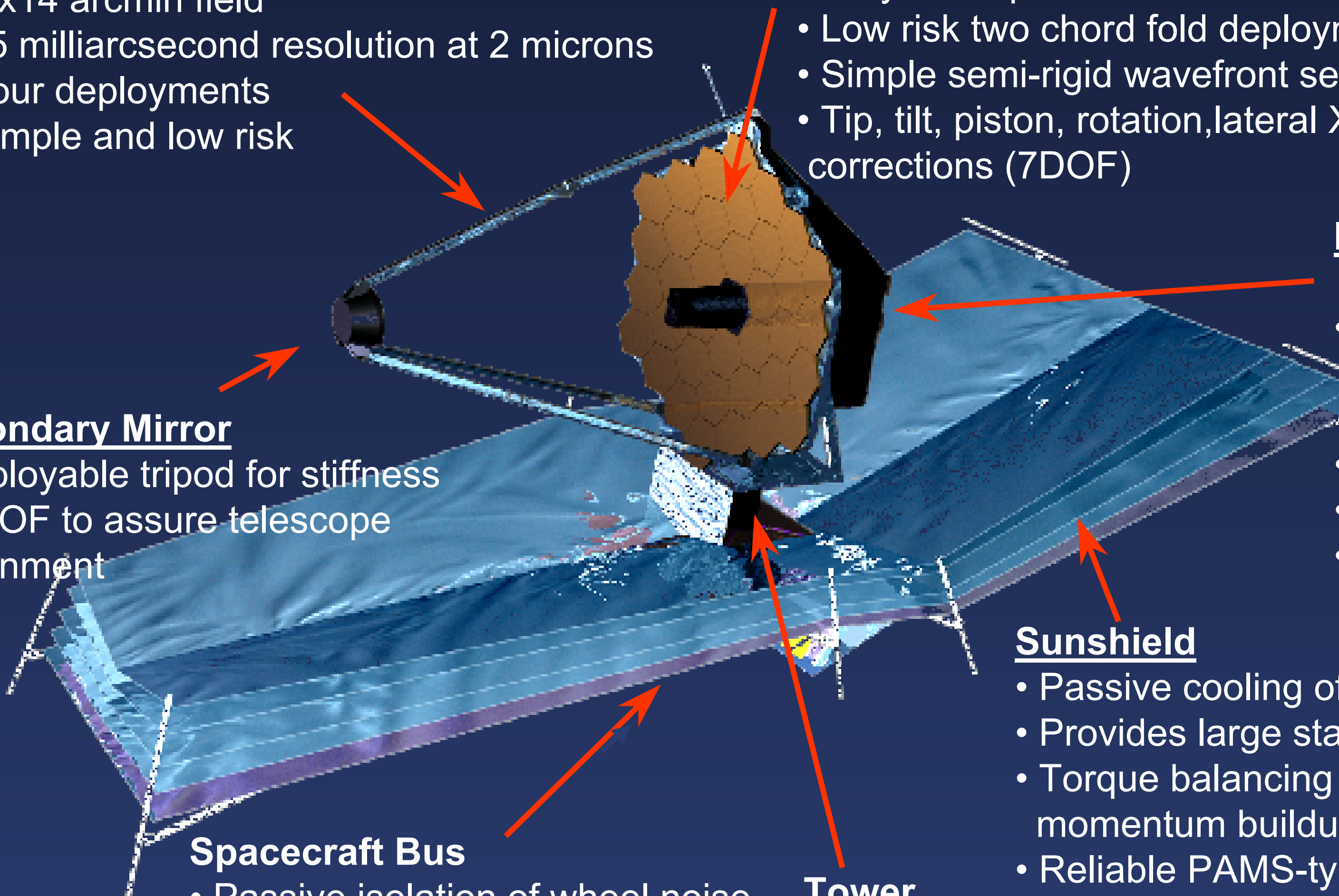


Edwin Hubble Space Telescope

- 2.4m (94 inches)
- f/3
- 171 kg/m2
- 11,860 kg total
- First Light 1986

JWST will do for space-based astronomy what Palomar did for ground-based astronomy

JWST Observatory Architecture is Reliable and Robust



Optical Telescope Element
- 0.6-28 microns
- 10x14 arcmin field
- 75 milliarcsecond resolution at 2 microns
- Four deployments
- Simple and low risk

6.5 Meter Primary Mirror (PM) ($A_{eff} = 25m^2$)
- 18 (1.3 m) hex segments simplify mfg and design
- Beryllium optics
- Low risk two chord fold deployment
- Simple semi-rigid wavefront sensing and control
- Tip, tilt, piston, rotation,lateral X and Y, and radius corrections (7DOF)

Integrated Science Instrument Module
- 3 instruments (NIRcam, NIRspec, MIRI)
- Fine guidance sensor
- $23m^3$ volume
- 3-point interface

Secondary Mirror
- Deployable tripod for stiffness
- 6 DOF to assure telescope alignment

Sunshield
- Passive cooling of OTE to <40K
- Provides large stable FOR
- Torque balancing limits momentum buildup
- Reliable PAMS-type deployment

Spacecraft Bus
- Passive isolation of wheel noise
- Heritage components (12 yr life)
- ACS supports fine pointing

Tower
- Isolates telescope from spacecraft dynamic noise

JWST Deployment Video

[Video Not Included]

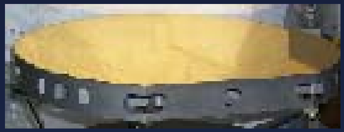
Mission-Critical Technologies Proven

Deployable Optical Telescope Assembly (DOTA) demonstrated cryogenic stability of a full scale primary mirror structure and mechanisms

OTE Isolator proved the required passive isolation

1/2 –Scale Sunshield Deployment Model showed membrane joining and management

Subscale Beryllium Mirror Demonstrator (SBMD) demonstrated required figure at cryogenic temperatures

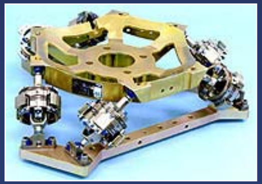


Wavefront Sensing & Control (WFS&C) Testbed verified all key WFS&C steps

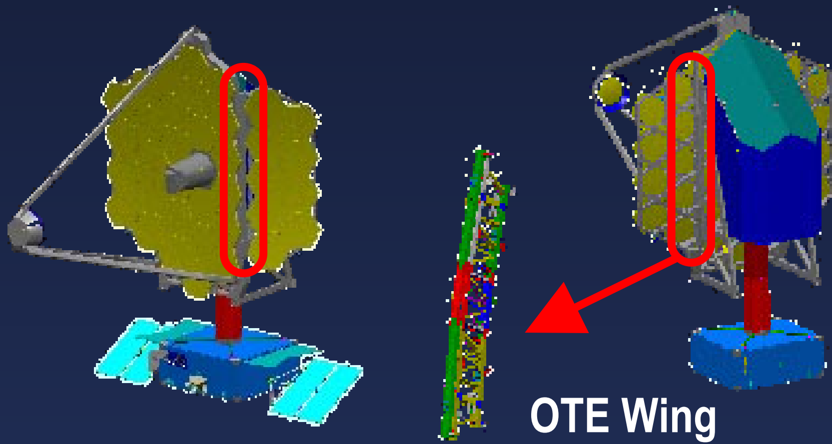
Mirror position actuator tested at 20K with required step size and resolution

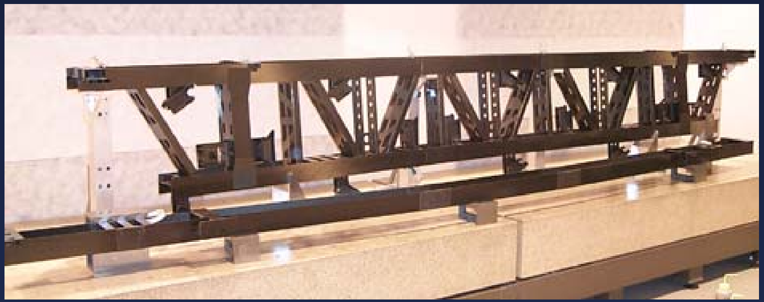
Advanced Mirror System Demonstrator (AMSD) proved fabrication techniques for ULE

Passive reaction wheel isolators proven on Chandra



Optical Telescope Element Backplane Demonstrator Retired All Major Backplane Risks

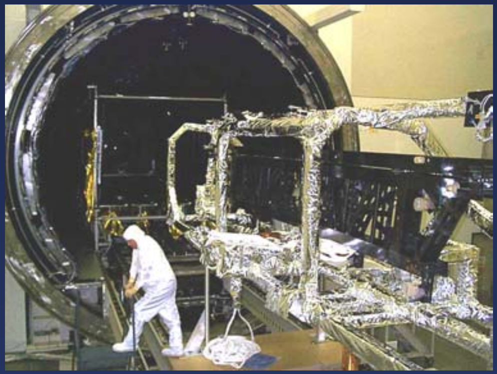




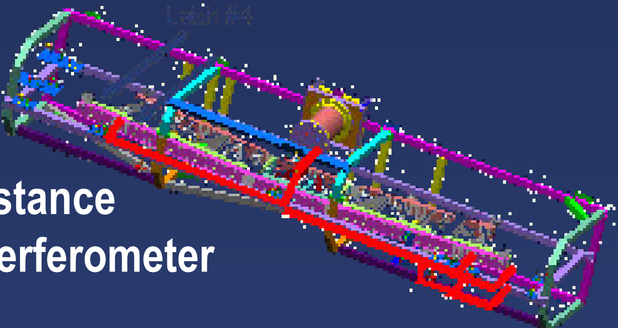
6m long OTE Wing boron hybrid structure

- **Boron hybrid material has excellent cryogenic temperature stability (0.1 ppm/K) giving good JWST performance margin**
- **Demonstrated latching system is nano-dynamically stable at cryogenic temperatures**
- **Experience in cryogenic thermal stability testing of large structures will be benefit to JWST testing**
  - Demonstrated thermal sensing to a resolution of 10 mK and an accuracy of 100 mK
  - Applied controlled temperature changes and varied the cool down rate

The largest precision structure ever cryogenically tested



Developed cryogenic temperature compatible distance measuring interferometer system



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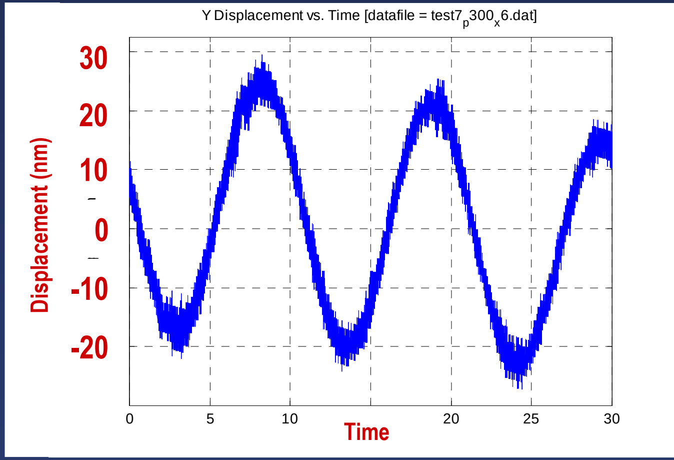
Backplane Deployment Mechanisms Meet Telescope Requirements

Room temperature nano-dynamic stability testing demonstrated required performance of < 10 nanometers lurching at >100x thermal and dynamic stresses

Demonstrated deployment and repeatability requirements met using flight-like mechanisms in test fixture.

Requirements driven by wavefront sensing and control capture range and mirror positioning actuator travel



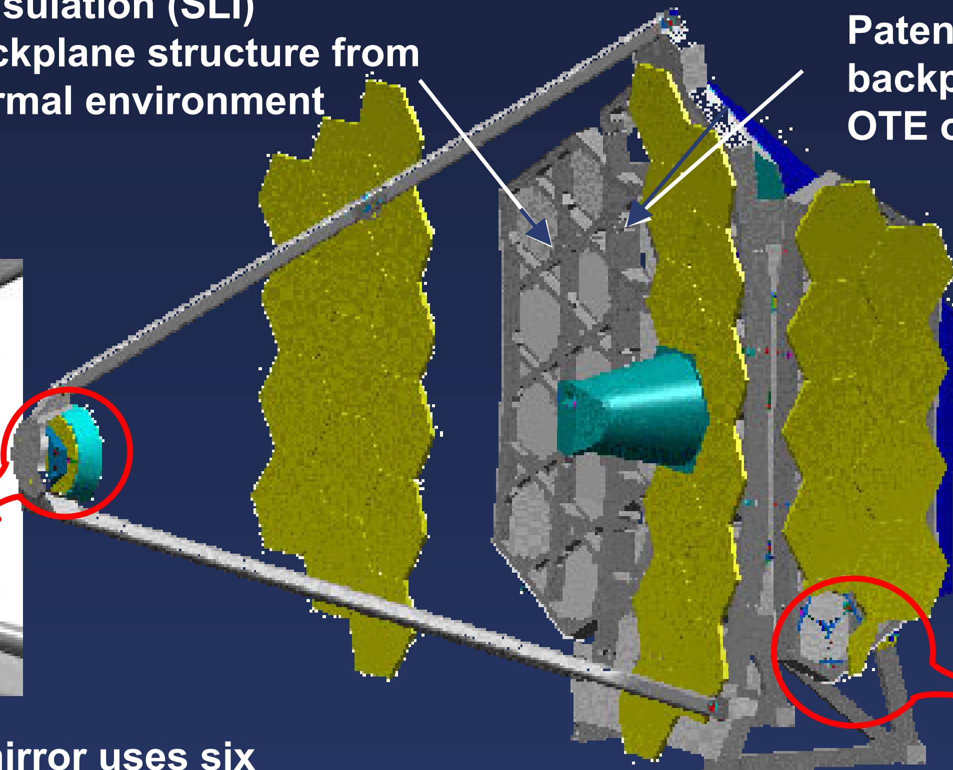
Dynamic cycling at 1000x flight loads showed no nano-lurching

Subsequent cryo testing confirmed performance

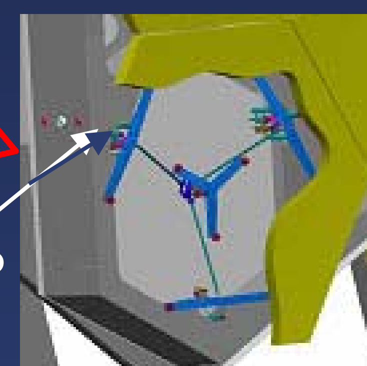
Thermally Stable Backplane Structure Supports Optical Segments

Single layer insulation (SLI) decouples backplane structure from sunshield thermal environment

Patented Boron/M55J GFRP Hybrid backplane provides low CTE over OTE operating range



- Full scale test (DOTA) over operating range
- Measured stiffness and CTE properties at Temp (CTE< 0.1 ppm/K)



Secondary mirror uses six actuators in a hexapod configuration, provides margin and redundancy for WFS&C

Primary mirror segments attached to backplane using actuators in a simple three-point kinematic mount

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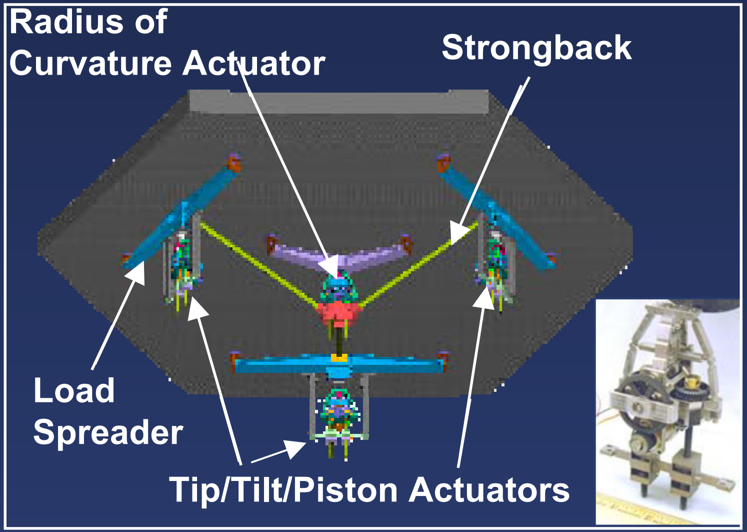
PM Semi-Rigid Hex Segments a Key Enabler of the Observatory Optical Performance

Simplifies WFS&C (126 actuators)

- Tip, tilt, piston, rotation, translation, and ROC control
- Rigid body motion is independent of radius of curvature control
- Rigid body corrections do not induce surface distortions or stress



- Observatory optical quality (mid and high spatial frequency) is manufactured into segments
- Segments fully tested before OTE assembly
- Fabrication and performance demonstrated for baseline Be material
- Mirror architecture can use Be or ULE
- Efficiency in production - same physical structure reused
- Simplifies system optical performance end-to-end test at temperature prior to launch

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Optical Quality Hinges/Latches Developed for Secondary Mirror Support Structure

Mid-Hinge

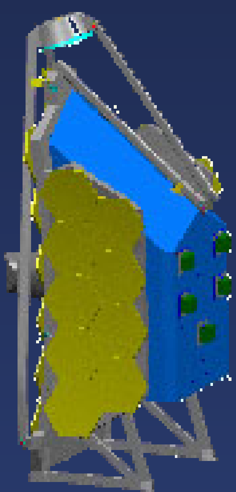
Hinge/Latches Tested to optical system requirements

- Position within capture range of mirror actuators
- Nano-stable
- Simple, reliable, small, light
- >25 years heritage for low risk

End-Hinge

Drive Hinge

- Typical 4 places



Stowed

Partial Deployment

Full Deployment

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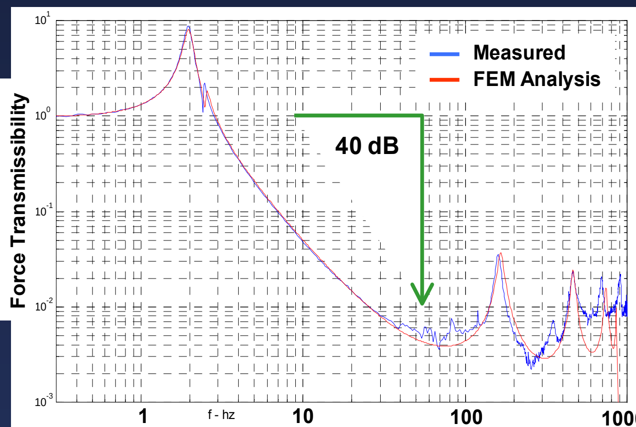
Passive Vibration Attenuation of 40 dB Achieved Over Reaction Wheel Range

JWST
6 nm
wavefront
budget

4 isolator beam struts support JWST deployed tower

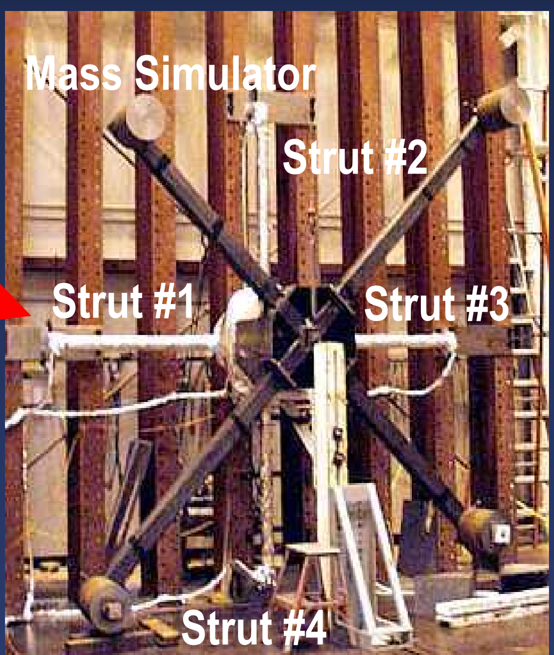
Force attenuation vs frequency shows excellent FEM correlation



Struts have constrained layer damping using viscoelastic material (VEM) flight proven on Chandra & EOS Aqua

System Test

- 1000 kg mass and moment of inertia simulator
- 5 of 6 isolator modes demonstrated
- >4% damping
- Hysteresis negligible to lab noise floor <250 nm, or <40 mas on sky

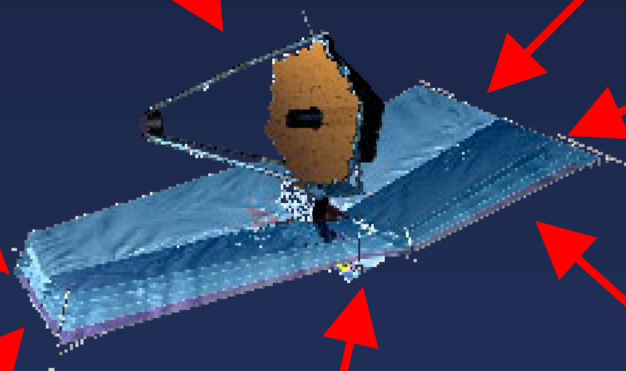


"V-Groove" Radiator Sunshield is Efficient

5 layer "V" shaped geometry very efficient at rejecting heat::
300 kW input from Sun, 23 mW watts out to telescope

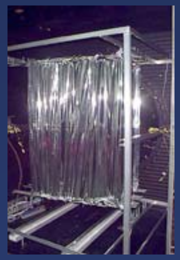
0.1K OTE thermal stability over wide field of regard for 10 year life

Testing verified tear propagation resistance up to 8000 psi tension from 27K to 300 K



Resistant to radiation effects

Testing showed good tolerance to wrinkles and contamination



Kapton membranes have VDA on telescope side and Si on sun side of two membranes toward sun

Balanced 3-plane design produces minimum momentum buildup over entire field of regard

Equivalent to an SPF of 10 million

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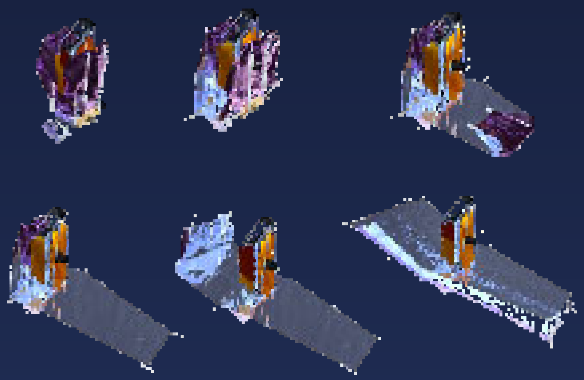
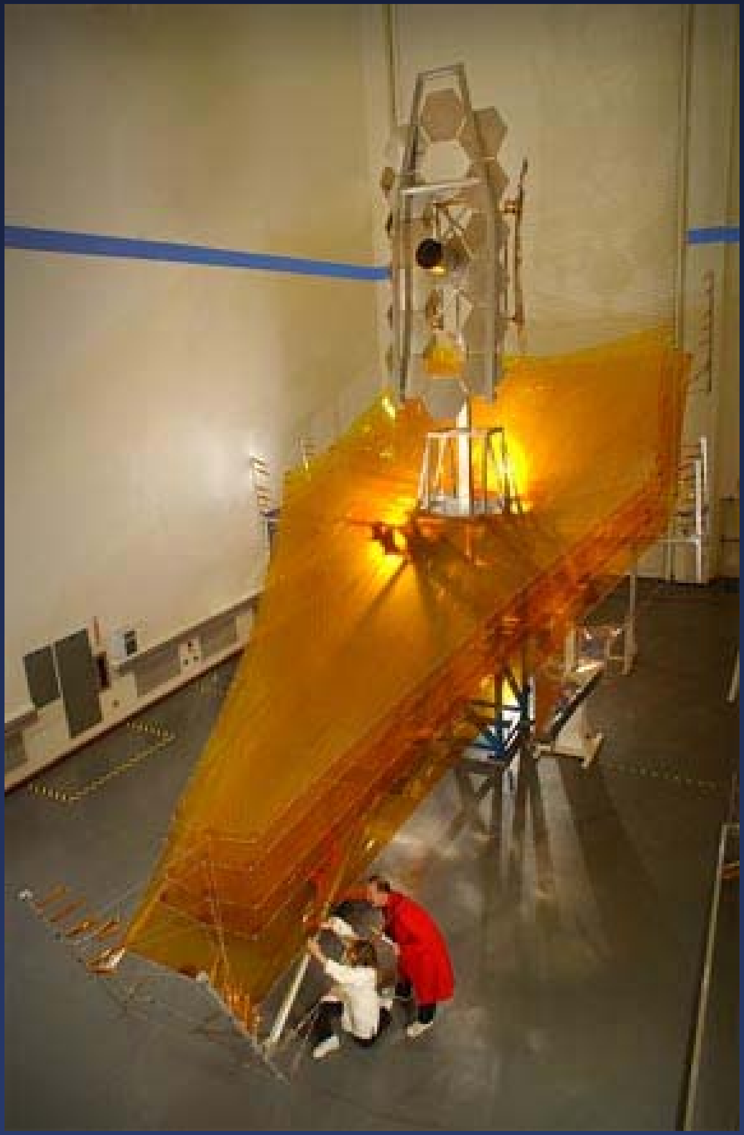
½ Scale Sunshield Demonstrates Stowed & Deployed Concept Feasibility

½ scale model stowed



JWST sunshield deployment

- Stows in 4.5m payload fairing. Deploys to 10m x 26m (size of a tennis court)
- Stow/deploy concept same as flight proven mesh antennas
- Minimum folding and mechanical working of membrane material
- Demonstrated producibliity and membrane management



½ scale model deployed

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JWST Will Demonstrate Many of TPF's Technology Needs

Technology	TPF Needs	JWST Provides
Large, lightweight Optics	√	√
Low cost mirror production	√	√
Precision deployable structures	√	√
Formation Flying	√	
Low temperature materials	√	√
Active vibration isolators	√	
Passive vibration isolators	√	√
Cryogenic Dampers	√	√
High contrast imaging (>10^6)	√	
Interferometric testbeds	√	
Wavefront sensing and control	√	√
Large format detectors	√	√
IR filters and substrates	√	√
Advanced cryocoolers (4-6K)	√	
Cryogenic opto-mechanisms	√	√
Lightweight, compact actuators	√	√
Superconducting Electronics	√	
Deployable solar & thermal shields	√	√
Hi-torque/capacity momentum wheels	√	

Enabling Technology

Enhancing Technology